USING LOCATION-BASED TECHNIQUES FOR COST CONTROL

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ABSTRACT

Performance measurement is an important component of lean-based management systems, however cost management systems or analysis have largely been applied at a high level and have not attempted to measure or model the production cost impacts of disruption on a lean project. While it is important to develop systems for practical site management, it is equally important to ensure that such systems can accommodate mainstream performance measurement systems. In this paper, the performance system known as Earned Value Analysis is adapted to a location-based method for planning and controlling work known as flowline or line-of-balance.

The resultant method for forecasting cash flow, modeling the costs of interference and controlling costs, is described. The method is compatible with location-based scheduling methods. It uses location-based quantities and their unit prices as starting data. Because the location-based quantities are also used in developing the flowline schedule, the start and finish date for each quantity is also known. This information can be used to calculate cash flow more accurately than previously. In the preplanning phase, quantity estimates and estimated prices are used to create a location-based cost estimate. During the production phase, more accurate quantity data is available and prices from contracts can be used directly to arrive at a first cost forecast, before commencing the work. When the work is being done, cost controlling can be done by surveying the actual quantities of each location. The cost forecast is then updated based on these actual quantities and using the contract prices. The location-based schedule forecast can be used to forecast overhead costs and to forecast costs of interference.

The paper contributes to our understanding of monitoring and control in a flowline-based management system in a lean-construction methodology. It also demonstrates that effective location-based control of the payment system allows better management of sub-contractors during production.

KEY WORDS

Cash flow, Earned value, Cost forecasting, Cost control, Flowline, Location-based.

INTRODUCTION

Lean construction is a philosophy of production, and one which is making significant and growing changes in the way that we build. There is no need to introduce the lean construction approach in this conference, nor is there need to explain in detail the various methods which have been proposed for managing construction work according to lean principles. However, an overview of the papers presenting these various ideas, models and case studies, generally make the claim that the consequence of poor management of the construction process will be increased cost—as well factors which have as their consequence increased cost, such as: as longer production times and reduced quality.

Koskela's interpretation of Ronin (Koskela 2004), even though discussing the concept of 'making do' as the eighth category of waste, delightfully summarizes the cost chain as follows: *"Regarding technical consequences, the starting*

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point is in an increase in processing time *and its* variability *caused by making do. The increased variability leads to* more working-in-process*, or equivalently to* longer lead times*. The increased processing time leads to a* decline in productivity *and to* more operating expenses (emphasis by Koskela 2004). Here is a clear statement that inefficient production leads directly to cost, and a far reaching explanation.

This obfuscates the real cause. More work-in-progress, greater operating expenses and reduced efficiency are blamed. Yet these are higher level terms and few would dispute the underlying causes, of double-handling, mobilization and demobilization, increased effort per unit of production. Interestingly, while there is a great deal of literature in the lean construction body of work on productivity and other higher level issues, there is relatively little dealing with the quantification or modeling of direct cost.

Cost management must not be isolated from managerial functions and Kern and Formoso (2004) argue that traditional cost management is strongly based on the transformational view of production, by quantification of finished elements, and is not suitable for lean construction—where flow activities are recognized in the cost system. Kern and Formoso's work proposes a composite costing system, with the particular method chosen according to circumstance. However, the proposal remains aloof from detail, utilizing holistic techniques to assess the impact of the schedule or method of work. Selected techniques are operational costing (traditional approach), target costing (product development emphasis) and S curves (integrated program and cost). These do not unearth the gritty detail of operational issues and costs—in the way that a lean focus on flow demands. Similarly, Ballard and Reiser's (2004) extremely useful case study of target costing, ignored the process costs in the analysis.

Table 1: Quantity and cost data of the hypothetical example project

				Location			
	Item	**Consumption (man hours/m2)**	**€ / units**	**1**	**2**	**3**	**Unit**
SCHEDULE TASK 1							
	Quantity 1	2	40	56	54	23	M2
	Quantity 2	3	60	43	23	43	M2
	Quantity 3	1	20	50	40	20	M2
Manhours / location				291	217	195	Hrs
Cost / location				5820	4340	3900	€
TOTAL MANHOURS		703	Hrs				
TOTAL COST		14,060	€				
SCHEDULE TASK 2							
	Quantity 4	0,1	3	90	120	150	M2
	Quantity 5	0,3	5	100	200	300	M2
	Quantity 6	0,6	9	400	500	200	M2
Manhours / location				279	372	225	Hrs
Cost / location				4370	5860	3750	€
TOTAL MANHOURS		876	Hrs				
TOTAL COST		13,980	€				
SCHEDULE TASK 3							
	Quantity 7	2	80	300	100	50	M2
	Quantity 8	1,5	60	90	70	100	M2
	Quantity 9	1	40	120	30	40	M2
Manhours / location				855	335	290	Hrs
Cost / location				34200	13400	11600	€
TOTAL MANHOURS		1480	Hrs				
TOTAL COST		59,200	€				

It may therefore be seen that while cost is universally seen as a justification for lean methodologies, researchers have not been able to analyze or model the detailed costs of production which lead to cost reductions under a lean methodology. One can't help wondering that, if this were done convincingly, the debate about the value of lean production methodologies might move from the realm of passion and philosophy, into the clarity of detailed and sum cost analysis.

This paper is an attempt to introduce a method for modeling cost of production such that production which does not follow flow-principles may be cost compared with that which does. Previous attempts to model the system have tended to focus on the applicability of certain principles of lean production to construction or have focused on simulating time and the impact of interruption (for example Al-Sudairi 2004). Such dynamic system approaches focus on the impact of the management philosophy through its impact on overall time, with the valid underlying assumption that more time equates to higher cost.

There are divergent views on how work should be planned and managed according to lean principles, and while process costs could be modeled in any lean production system, this paper adopts the principles of Flowline (Kenley 2004), defined as location-based activity management driven by the principle of continuous use of work resources. Flowline is a management philosophy for construction production, otherwise known as: 'Line-of-balance', 'Construction planning technique', 'Vertical Production Method', 'Time-Location Matrix model', 'Time Space Scheduling method', 'Disturbance scheduling' and 'Horizontal and vertical logic scheduling for multistory projects' ((Harris and Ioannou 1998). (Kenley 2004) reintroduced the most evocative term for a Lean thinker, that of 'Flowline' (from Mohr 1991)[3].

Given the flowline approach, then an alternative to dynamic systems can come through the use of flowline software. For this paper, the DYNAProject software is used. While not a dynamic system as such, it does allow the visualization of production effects, and can be altered to model cost impacts. However, in order for the detailed costs of production to be simulated, a method must first be developed.

This paper presents a method for modeling production detailed cost impacts of inefficient production in a lean construction system. The method adopted is Earned Value Analysis applied to location-based management using flowline. The result is the development of a tool which, perhaps for the first time, models the detailed cost impact of both the planned interruptions to work flow and also the consequences of disturbances to the plan.

LOCATION BASED COST ESTIMATE AND SCHEDULE AS STARTING DATA

The Location based cost control method need location based quantities as their starting data, thus the best starting point is an appropriately measured Bill of Quantities. If each quantity also has a unit price and labor consumption attached, it is possible to calculate cost and man hours needed to complete the work in any given location.

In location based scheduling, the quantities of a single schedule task can be located in multiple locations. This is enormously powerful for planning work, as one activity in location-based methods can represent many activities in more traditional methods such as Critical Path Method (CPM). A schedule task is composed of a chain of quantity items that can be done by the same crew and which will all be finished in one location before moving on to the next location; a primary requisite of flowline production. The duration in each location is calculated by calculating the man hours needed to complete all the quantities in the location and then dividing by resource quantity and shift length in hours. The flowline production method aims at optimizing the flow of resources through all the locations, maintaining even resource use without unnecessary breaks. This allows the target cost of any location of the task, and its timing, to be calculated automatically, because cost estimate quantities are directly scheduled.

The starting data for a simple, hypothetical project, with three locations and three schedule tasks is shown in table 1. Each schedule task contains three quantities and flows through all the locations in the same sequence 1→2→3. The preceding schedule task must finish all work in a location before the succeeding schedule task can enter. Each schedule task includes a labour consumption rate (man hours per unit) and a cost per unit.

The schedule planned based on the starting data is shown in figure 1 both in Gantt chart and flowline format. The crew sizes have been selected so that the slopes are approximately the same.

3 Harris & Ioannou (1998) also identified the terms used in engineering construction such as highways, pipelines and tunnels, as 'Time versus distance diagrams', 'Linear balance charts', 'Velocity diagrams' and 'Linear scheduling'. also identify 'Horizontal and vertical scheduling', and 'Multiple repetitive construction process'—but aimed these at the specific case of vertical replication repeated in multiple buildings.

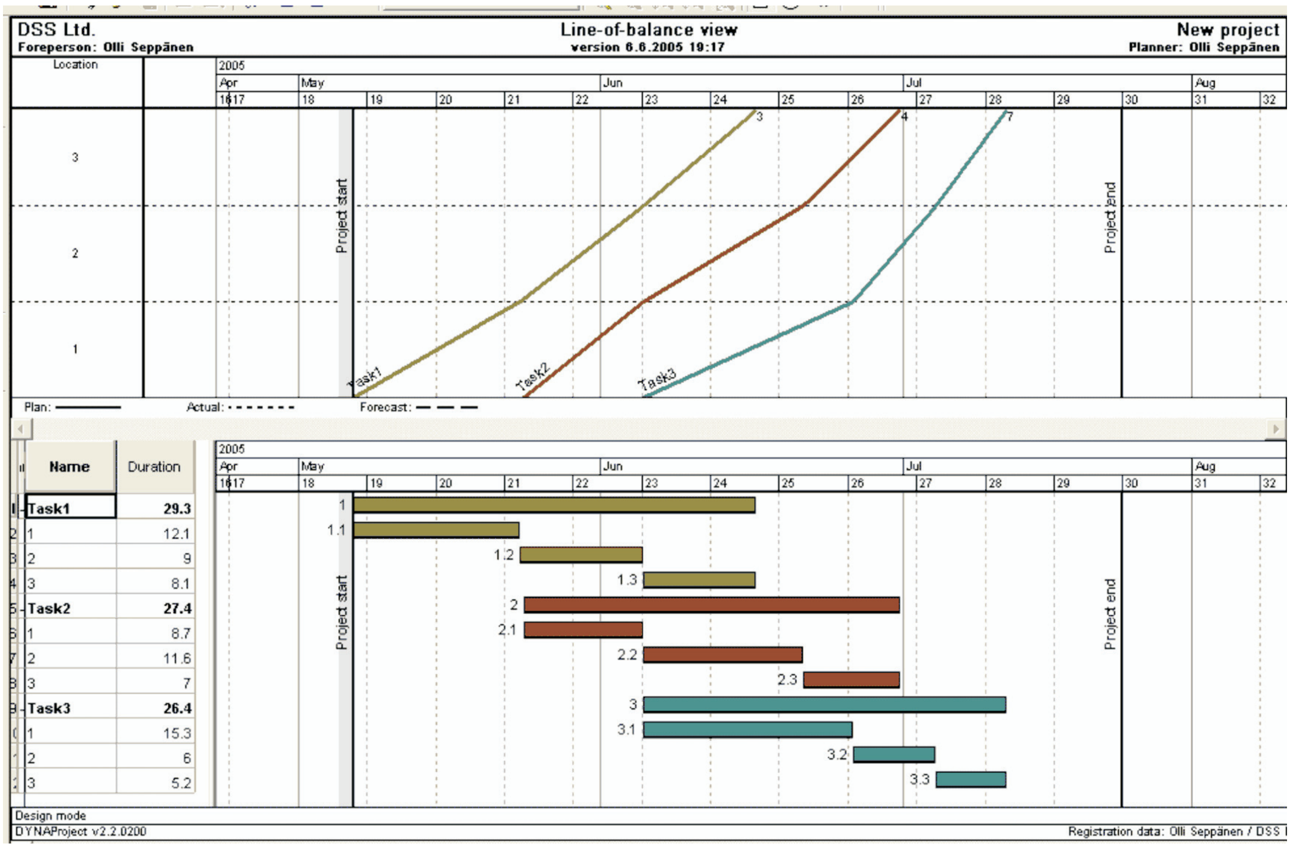

Figure 1: Schedule of the hypothetical example project in flowline and Gantt chart format

MODELLING TIME-DEPENDENT OVERHEAD COSTS

Overhead costs vary as a function of duration. They are usually proportional to the duration of the project, the duration of some particular tasks, or the utilization of a resource. For example, a project engineer might be present for the duration of the whole project. A mobile crane is present only when needed as a resource in some schedule tasks. In the developed location-based planning method, overheads may be applied in two ways, but arising from many sources. For each overhead cost factor, overheads have a unit price, which is multiplied by a time variable calculated from either the duration of the project or from the durations of selected schedule tasks.

In the simple example of this paper, let's assume that we have three overhead items each with a unit price of 100 € / shift. The first item's duration is calculated based on the whole project. The second item's duration is calculated based on the effective duration of tasks 1 and 2 and the third item's duration is calculated based on the durations of tasks 2 and 3. Table 2 shows the durations and planned costs of these overhead quantities. Note: the duration is not the sum of the durations for each task, but rather the envelope duration of both tasks.

Table 2: Costs of overhead items based on the schedule

Overhead Quantity	Duration basis	Unit price	Shifts	Total cost €
1	Project	100 €	48	4,800
2	Tasks 1,2	100 €	40	4,000
3	Tasks 2,3	100 €	36	3,600

PAYMENT SCHEDULE BASED ON COST TYPES AND QUANTITIES

The timing of payments varies between subcontractors, material purchases and to direct labour (Kenley 2004). Usually they can be divided into two types: time-based or milestone based payments. Time based payments most commonly occur monthly, but can also occur biweekly and bimonthly, for the work in progress. Milestone based payments are paid when a milestone has been reached (for example a given completion rate for the whole task or completing some locations).

Traditional CPM contract administrations systems are, as has been said, based on activities. Typically progress payments are based on percentage complete of the entire activity without reference to the amount of work in specific locations. Essentially this arises because standard methods of measuring Bills of Quantities ignore locations, and because scheduling systems are activity-based rather than location-based. An alternative common in Finland is for payments to be linked to completion of locations. The merits of this are beyond the scope of this paper, but link back to the principles of lean construction, but include completing work prior to hand-over and constraining flow of work.

The example used in this paper has enough information to calculate estimated payments regardless of the payment type. This is because the quantities, start and finish dates and production rates in each location are known. Thus completed quantities in any location can be calculated easily for any given date (assuming that all the quantities of the task are completed linearly in a location). These completion rates are used to calculate the amount of payment if the location has not been completely finished.

Interestingly, this level of control removes some of the underlying reasons for requiring Earned Value Analysis—while greatly empowering it in practice.

In this paper's example let us assume that task 1 is paid monthly, task 2 is paid on completion of each location, task 3 is paid biweekly and all overhead tasks are paid monthly. Table 3 shows the payments. For simplicity, the example doesn't have pre- or post-payments.

Client payments to the General Contractor depend on the project type. They can be tied to milestone or fixed dates or progress of the work. Because the Finnish construction industry has widely adopted location-based planning and controlling tools, the clients will in the future tie the payment schedule to locations of the most critical schedule tasks. However, mostly payment schedules are tied to completion rate of the schedule or fixed monthly payments. The timing of income payments can be modeled the same way as expenses, based on completion rates of quantities in locations regardless of the payment reason.

In this example, let us assume that the client wants the General Contractor to use location-based methods and pays 20 % in advance, 60 % based on location completions (each task weighted equally) and 20 % after all work is finished. Total contract is 120,000 €. This results in the income payments as shown in Table 4. The important component here is payment by location, which empowers a flowline (and therefore lean) management philosophy.

Table 3: Payments based on schedule and payment types

Task	Payment	Reason	Date	Amount €
1	1	Monthly	1.6.2005	8 640,00
	2	Monthly	1.7.2005	5 420,00
2	1	Location 1	6.6.2005	4 370,00
	2	Location 2	21.6.2005	5 860,00
	3	Location 3	30.6.2005	3 750,00
3	1	Biweekly	20.6.2005	22 026,68
	2	Biweekly	4.7.2005	22 400,99
	3	Biweekly	18.7.2005	14 773,33
Overhead task				
1	1	Monthly	1.6.2005	1 800,00
	2	Monthly	1.7.2005	2 200,00
	3	Monthly	1.8.2005	800,00
2	1	Monthly	1.6.2005	1 800,00
	2	Monthly	1.7.2005	2 200,00
3	1	Monthly	1.6.2005	600,00
	2	Monthly	1.7.2005	2 200,00
	3	Monthly	1.8.2005	800,00

Table 4: Table of income payments

Reason	Date	Payment
Prepayment	6.5.2005	24 000,00 €
Task 1, location 1	24.5.2005	8 000,00 €
Task 1, location 2	6.6.2005	8 000,00 €
Task 2, location 1	6.6.2005	8 000,00 €
Task 1, location 3	16.6.2005	8 000,00 €
Task 2, location 2	21.6.2005	8 000,00 €
Task 3, location 1	27.6.2005	8 000,00 €
Task 2, location 3	30.6.2005	8 000,00 €
Task 3, location 2	5.7.2005	8 000,00 €
Task 3, location 3, project finished	12.7.2005	32 000,00 €

PLANNED CASH FLOW

Because the dates and amounts of payments are known, it is straightforward to draw a planned net cash flow curve by assuming a payment delay for expenses and incomes. In the example for this paper, the net cash flow is positive almost the entire time, as shown in figure 2. However, there is a single dip of the cumulative curve below zero line in the middle of July for a few days.

The tools presented thus far allow the optimization of project cash flow in the preplanning or estimating stage.

COST FORECASTING DURING PROJECT

Costs are committed during various stages of the project. Usually only the income payment schedule is fixed before the project begins. Actual unit

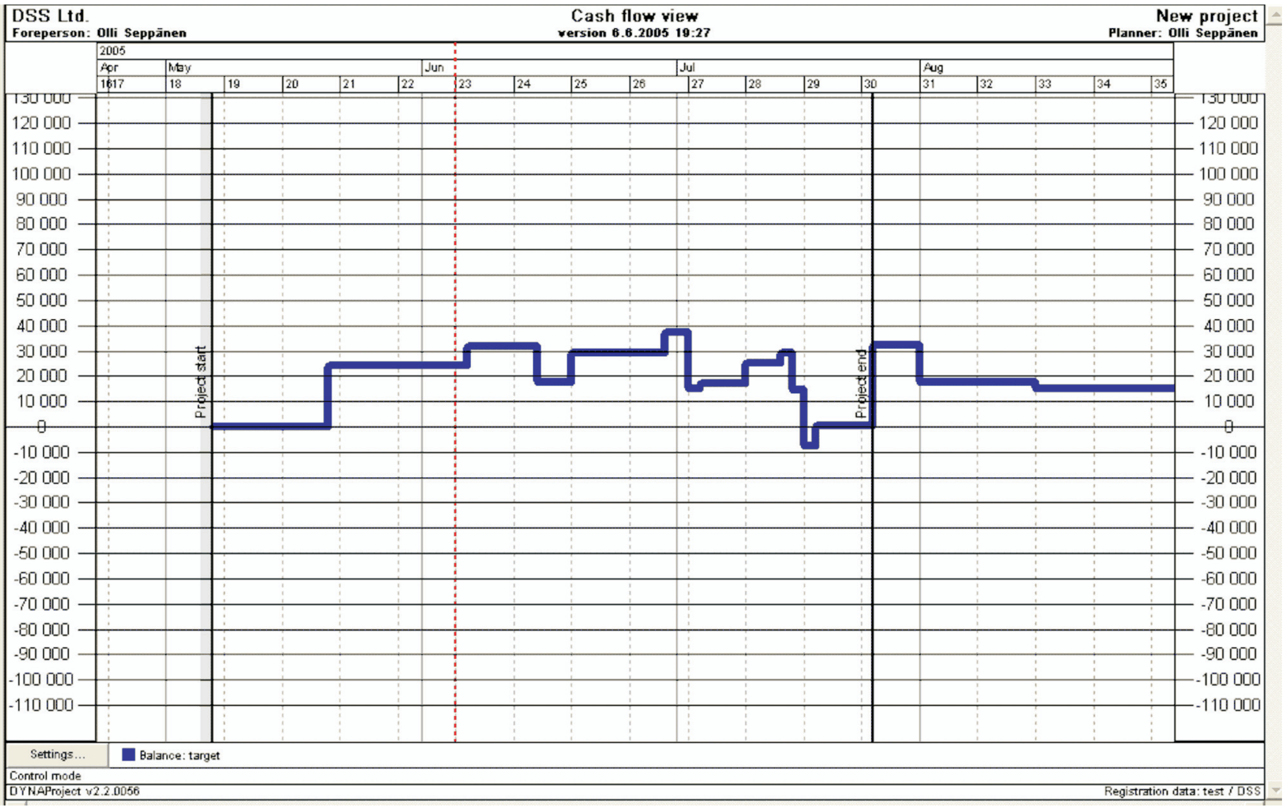

Figure 2: Project net cash flow

costs are fixed only after an agreement is made with a subcontractor, material is ordered or men are hired to do the work. Quantities are not usually accurate in the preplanning phase. There may be mistakes in the take-off, the design may not be completed or change orders may occur. The location-based cost forecast takes into account these issues by always using the most accurate information available:

- in the estimating stage prior to contract the cost estimate is used;
- after agreement when the bill has been rated, the agreed unit prices can be used;
- and when the project is in production, on the actual quantities in each location (rather than the measure if there is variance) along with the contract rates may be combined with the adjusted schedule - to forecast based on actual production rates.

The cost forecast is calculated separately for each schedule and overhead task. The total project cost forecast is the sum of the schedule and overhead task forecasts.

FORECAST 1: USE THE ADJUSTED TARGET

The initial cost estimate is used in forecasting as long as there isn't more accurate information available. This is the case when subcontract or material deliveries haven't yet been agreed on. The cost forecast can be adjusted if earlier tasks have consistently exceeded their target cost and over 30 % of the project has been completed (Pekanpalo 2004).

FORECAST 2: USE THE AGREED UNIT PRICES AND THE CURRENT INFORMATION ABOUT QUANTITIES

The second forecast is based on agreed unit prices or total price for the subcontract and the current information about quantities. If the quantities have changed, this has two effects on the cost forecast: the schedule forecast changes if the same amount of resources is used as in the original plan and the cost of the quantity changes. Schedule forecast affects the forecast time of the payment and the forecast cost of the overhead tasks. By using the same method as applied when calculating the original target estimate, it is straightforward to calculate the adjusted cost forecast. The modeling of interference effects on other trades are described below in section about cost of interference.

FORECAST 3: USE THE ACTUAL PRODUCTION RATE INFORMATION AND ACTUAL QUANTITIES

After production has started on a task, actual status information can be used in forecasting, in the same way that Earned Value Analysis uses percentage completion of activities. Actual start date, end date and quantities can be used to estimate the average actual production rate in a location. This production rate can be used in making the schedule forecast for the succeeding locations. The actual quantities themselves are useful in making cost forecasts for the rest of the task. If the quantity exceeds planned quantity in a location, it can be assumed that the quantity overrun occurs also in the succeeding locations if control actions are not taken. When actual information for at least one completed location is available, the forecast is calculated using the following steps:

1. For each quantity item, calculate the quantity overrun ratio: total actual quantity / total planned quantity
2. Calculate forecast quantity in each location which has not been finished: quantity overrun ratio current estimate of quantity
3. Calculate the forecast cost of the task: sum of forecast/actual quantities agreed unit prices

The method warns of impending cost overruns earlier than using information from accounting because it is real time and based on actual quantities in each location (Pekanpalo 2004).

FORECAST 4: COST OF INTERFERENCE

Lean construction methods recognize the impact of waste, or non-value adding activities, in the production process. Interruptions in work flow cause direct and indirect waste which incur cost. The main assumption of location-based planning and controlling systems is that breaks of resource flow either cost money or decrease predictability because of return delay risk. Projects currently normally choose to accept the risk of return delays rather than added direct cost. For modeling the impact of delay or variance from the plan, and the preceding activity causes the successor to break resource flow, the schedule or the cost forecast is modified, depending on the chosen option:

1. If extra cost is chosen, the subcontractor or the workers are compensated their normal hourly wage for idle time (resource amount hourly cost amount of interrupted hours). This is equivalent to requiring the workers to sit in the shed—a mechanism familiar to lean construction researchers.
2. If added risk is chosen, the schedule forecast of the successor is shifted forwards until it can continue without interruptions until the next milestone of the subcontractor.

FORECAST 5: OVERHEAD COSTS

After all the schedule forecast modifications have been done, the durations of the overhead tasks are recalculated based on the schedule forecast and their cost forecast is based on the agreed on unit prices.

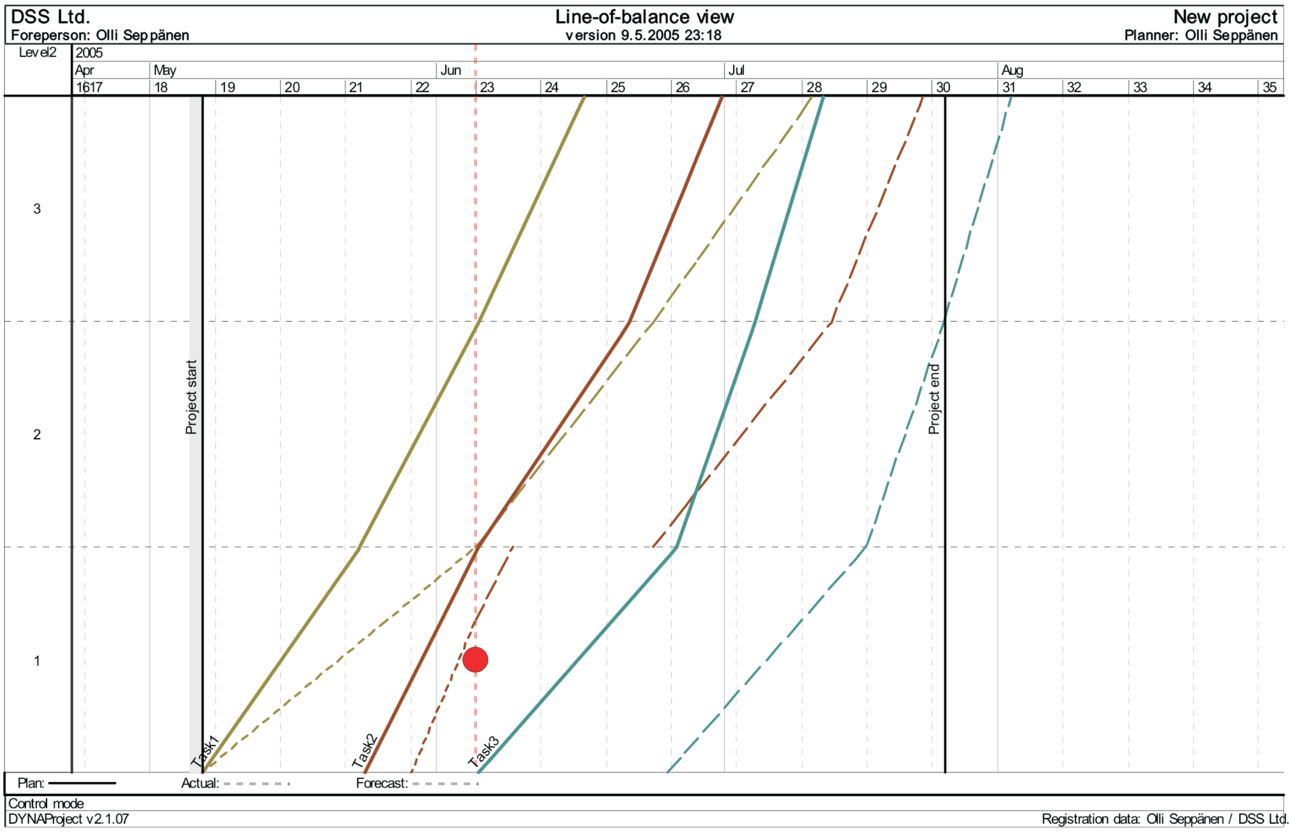

Figure 3: Detail of cost forecast of interference

Table 5: Cost forecast of the sample project

	Item	Consumption (man hours/m2)	€ / units	Location 1	Location 2	Location 3	Unit
SCHEDULE TASK 1							
	Quantity 1	2	40	75	54	23	M2
	Quantity 2	3	60	50	23	43	M2
	Quantity 3	1	20	60	40	20	M2
Manhours / location				360	217	195	Hrs
Cost / location				7200	4340	3900	€
TOTAL MANHOURS		772	Hrs				
TOTAL COST		15,440	€				
SCHEDULE TASK 2							
	Quantity 4	0,1	3	90	200	150	M2
	Quantity 5	0,3	5	100	250	300	M2
	Quantity 6	0,6	9	400	570	200	M2
Manhours / location				279	437	225	Hrs
Cost / location				4370	6980	3750	€
TOTAL MANHOURS		876	Hrs				
TOTAL COST		13,980	€				
SCHEDULE TASK 3							
	Quantity 7	2	80	300	100	50	M2
	Quantity 8	1,5	60	90	70	100	M2
	Quantity 9	1	40	120	30	40	M2
Manhours / location				855	335	290	Hrs
Cost / location				34200	13400	11600	€
TOTAL MANHOURS		1480	Hrs				
TOTAL COST		59,200	€				
TOTAL COST OF QUANTITIES		89,740	€				
Overheads		**Duration basis**	**Unit price**	**Duration**	**Total cost**		
OVERHEAD QUANTITY 1		Project	100 €	62 shifts	6 200 €		
OVERHEAD QUANTITY 2		Tasks 1,2	100 €	56 shifts	5 600 €		
OVERHEAD QUANTITY 3		Tasks 2,3	100 €	47 shifts	4 700 €		
TOTAL COST OF OVERHEADS		16 500 €					
TOTAL COST OF INTERFERENCE		**960,00 €**					
TOTAL COST FORECAST		107 200,00 €					

EXAMPLE

The example project has proceeded to Friday of week 22. To make the example simpler, it is assumed that the agreed unit prices are the same as planned. The subcontractor of task 1 provided two workers instead of the planned three and the actual quantities in the first location were larger than planned, so there has already been a schedule deviation of two weeks. It is known beforehand that the quantities of task 2 had been underestimated in the second location. However, the subcontractor started one week after the scheduled start date with the correct amount of resources and has so far achieved the planned production rate. Figure 3 shows graphically the current situation.

Unless the management reacts, the subcontractor of task 2 must be compensated for a waiting time of two weeks. Unless the previous tasks can be accelerated there is no point in getting the sub-contractor of task 3 to the site until week 26 because otherwise he would also have breaks. The cost forecast for the project is 107,200 €. Of this total, 89,740 € comes from quantities, 16,500 € from overheads, 960 € for interference. The original cost estimate was 99 640 € so the project so the forecast is 7,6 % over budget. Because the forecast of the final task is after deadline there may be additional penalties. Also the times of payments have changed. Table 5 shows in detail the calculations of the cost forecast.

CONCLUSION

One of the greatest problems with site management is poor sub-contractor performance, in particular getting them to complete work in locations progressively. Leaving incomplete work is one of the major factors driving the failure of following trades to complete their work.

One of the primary reasons is the payment for percentage complete problem. Traditional contractual methods pay sub-contractors progressively based on their percentage complete. Unfortunately, this means that it is far more profitable for them to complete 80% or 90% in each location and then progress to the next, also completing 80% to 90%. Getting them to return and complete the work in time for the next trade is often a real struggle.

Management of payments by location drives completions and therefore supports lean construction. The best solution is to only pay a sub-contractor progressively for work within the allocated location. Work done out of sequence will not be recognized or paid. Thus they must complete all sequential work before they would get paid. Payment is a major motivator of behavior!

The cost system demonstrated in this paper is a major contribution to lean management strategies which adopt a flowline, or location-based management methodology.

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